Quantifying and Financing Food Waste Reduction in Singapore's F&B Sector

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INTRODUCTION 01

Food waste has become a core issue, restricting the sustainable development of the global food system. According to UNEP (2024), the total amount of global food waste was 1.05 billion tons, accounting for approximately one third of the total food supply for human consumption worldwide. On average, there were 132 kilograms of food waste per capita per year. This issue not only contributes to a large amount of resource misallocation and waste but also brings three negative externalities.

Social
- 783 million people going hungry
- One third of food is lost/wasted

Environmental
- Greenhouse gas: 8% - 10%
- Nearly 30% of the world's agricultural land

Economic
- Throwing away of more than US$1 trillion worth

Singapore: over 90% of food supply relied on imports from oversees.

755,000 tons Accounting for about 11% of the nation' s total food waste

18% recycle The rest was mainly incinerated, with ashes sent to the Semakau Landfill, the only landfill in Singapore, which is projected to be full in 2035

40% Commercial and industrial sources accounted for about 40% of nation' s total food waste

28% Food service, including restaurants and hotels, as an important commercial source, nation' s food waste

Study aims:
- Identifying and quantifying observable and measurable stages of food waste
- Estimating the carbon impact of different types of food waste
  - weight of food waste, information on food categories, and secondary emission factors
- Translating food waste measurement into practical insights
  - identify priority reduction links, optimize management processes, and formulate more targeted reduction strategies.

METHODS 02

This paper refers to a quantitative method from Scherhaufer et al (2018), whose key idea was that the environmental impact of food waste should not be calculated only from the disposal stage, but also should include all the life-cycle impacts that had already occurred before the food was wasted. In simple terms, the impact of a certain type of food waste can be understood as the weight of wasted food times the emission factors of the relevant life-cycle stages, plus the impact from waste treatment. Therefore, the later food is wasted along the supply chain, the higher its environmental impact becomes.

Environmental impact of food waste of a certain type
= Weight of the wasted food × Unit environmental impact of the food during the relevant life cycle stage + Impact from waste treatment

Waste in production = production impact + disposal impact
Waste in consumption = production + processing + transportation + disposal

Firstly, we have a different division of the stages for LCA;
Secondly, we will consider the disposal issue comprehensively at the end, rather than considering it at each stage separately.

	Source	Distribution & Procurement	Preparation	Consumption	Recovery
Description	Production = Farming / breeding / planting / fishing stage Processing = Processing of food before it enters the market	Warehousing and Inventory turnover Logistics for delivery to Singapore or supply chain nodes	Preparation of ingredients Processing / Cooking process gas, steam, and electricity consumption	Finished product delivered to the end consumers, until the consumers finish consuming it, generating food leftovers and packaging waste	Waste from food / food leftovers disposal
Emission factor include	Production & processing	Transportation	Preparation of ingredients	Food leftovers in the plate	Composting: wet
Assumptions	Food waste amount is unattainable, assume to be 0		Emission factor is unavailable ,assume to be 0		N/A

Image-based food waste mass composition estimation – AI Prompt

Step 1 Identify Ingredients
List all visible food waste categories, group minor items

Step 2 3x3 Grid Analysis
Divide bucket surface into 9 cells. Area%=cell/9

Step 3 Mass Estimation
Adjust area% into mass % by density, thickness, water content...

Step 4 Scale Reading
Read total weight, estimate mass per category

Step 5 Structured Output
Six column table + confidence & uncertainty

Work Example:
Mixed Rice - 12/05/2026

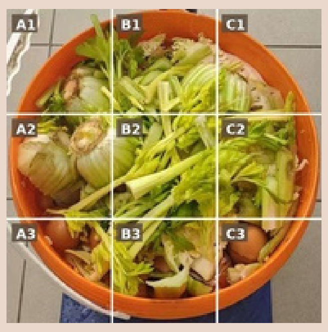


Fig.1 Raw input image supplied to AI prompt.

Step 1: Identify Ingredients

From the bucket photo, the AI identifies:
•Celery stems/leaves/bases.
•Cabbage / pale leafy vegetable scrap
•Brown eggshells / egg residues
•Mixed cooked scraps / small peels / residue

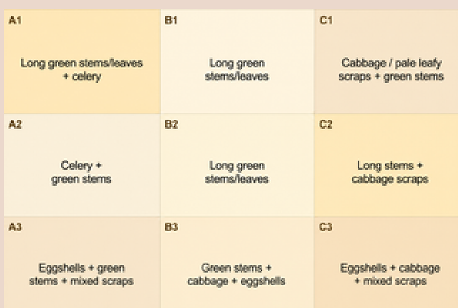
STEP 03 – Infer Weight % by Food Properties

Density - Heavier per volume (e.g. eggshells vs. leaves)
Water Content - High water = heavier than it looks (e.g. cabbage)
Colour - Visual cue for material type & likely density
Thickness - Thin leaves vs. thick stems changes mass

Area-to-Weight Formula

Weight% = Area% ×Density Factor × Water Content Adj. × Thickness Modifier

Step 2: 3x3 Grid Analysis



From each 3×3 grid cell, the AI estimates:
Visual pixel area occupied by each identified ingredient
Coverage % per grid cell (e.g. 60% celery, 30% eggshell, 10% cabbage)
Aggregate area share across all 9 cells → weighted grid average

Calculation

Daily Emission: Daily food waste weight × EF embedded
Emission Factor: EFembedded= Σ(Ingredient proportion ×Ingredient EF in different stage)

Emission Calculation Methodology (Scherhaufer et al., 2018)

		Source	Distribution & Procurement	Preparation	Consumption	Recovery/Disposal
LCA Stage-Based	**Description**	Using food waste from each LCA stage and the emission factor for each LCA stage				
	Data Used	$FW_{Source}=0$	$FW_{D\&P}=0$	FW_{Pre}	FW_C	$FW_{Source}+FW_{D\&P}+FW_{Pre}+FW_C$
		-	-	Kitchen waste data	Plate Waste data	Kitchen + Plate waste data
		EF_S	EF_{Pro}	0		$EF_{Treatment}$
	Emission Calculation	$0\times EF_S$	$0\times(EF_S+EF_{Pro})$	$FW_{Pre}\times(EF_S+EF_{Pro}+0)$	$FW_C\times(EF_S+EF_{Pro}+0)$	$(0+0+FW_{Pre}+FW_C)\times EF_{Treatment}$

Each stage's waste carries all upstream accumulated emissions, waste discarded later in the chain has a higher embedded carbon emission

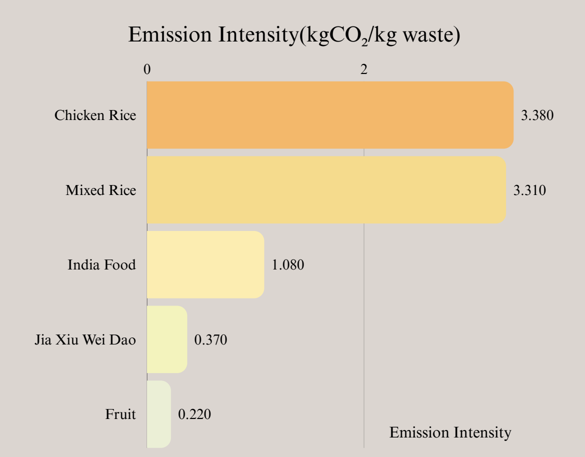
Field Observation Result

Source	Distribution & Procurement	Preparation	Consumption	Recovery
587.16 kg CO_2-eq	761.10 kg CO_2-eq	761.10 kg CO_2-eq Preparation's own emission factor = 0 (No energy data collected)	420.99 kg CO_2-eq	274.80 kg CO_2-eq

DISCUSSION & RECOMMENDATIONS 03

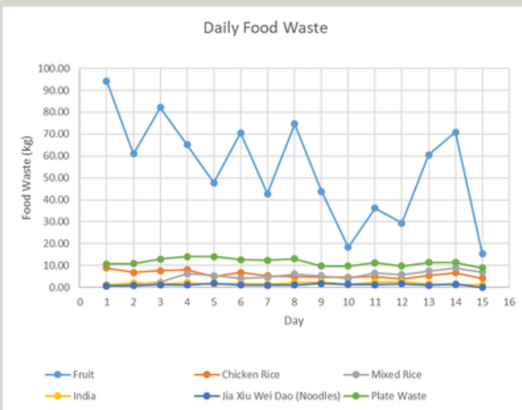
Finding 1 – **Jia Xiu Wei Dao:** Lowest Food Waste & Carbon Emissions among all surveyed outlets. Jia Xiu Wei Dao's superior performance stems from two factors. First, its menu is simple – noodle-based dishes with high ingredient overlap, reducing the need for diverse stock and cutting waste. Second, its waste is mostly leafy vegetable trimmings, which have a low emission factor of 0.37 $kgCO_2e/kg$ – far below that of animal-based waste. Together, these explain why the outlet recorded the lowest waste weight (17.9 kg) and lowest emissions (6.6 $kgCO_2e$) among all outlets. This shows how smart menu design and ingredient selection can reduce both waste and climate impact.

Outlet	Total Kitchen Waste (kg)	Total Emissions (kg CO_2-eq)	Emission Intensity (kg CO_2-eq/kg waste)
Fruit	812.90	178.8	0.22
Chicken Rice	87.90	297.13	3.38
Mixed Rice	76.50	253.31	3.31
India Food	26.60	28.61	1.08
Jia Xiu Wei Dao	17.90	6.62	0.37
Tray Return	172.98	420.99	2.43



Finding 2 – **Chicken Rice**: High Food Waste & Carbon Emissions despite a relatively simple menu. Despite a simple menu and good practices – using chicken meat for the main dish and bones for soup, with small portions that leave little plate waste – the Chicken Rice outlet recorded 87.9 kg of food waste and the highest carbon emissions (297.1 $kgCO_2e$) among all outlets. The main reason is that its waste is dominated by chicken bones, which are heavy, gain weight during cooking, and carry a high emission factor of 3.38 $kgCO_2e/kg$. This shows that even with full ingredient utilisation and portion control, the type of waste matters more than the amount when it comes to carbon impact.

Finding 3 – **Fruit Shop**: Highest Food Waste Volume , low Carbon Impact Relative to Waste Mass. The Fruit Shop generated the highest food waste weight (812.9 kg) among all outlets, yet its carbon emissions (178.8 $kgCO_2e$) ranked only third. This is because its waste is composed predominantly of fruit peels, cores, and off-cuts, which carry a low emission factor of 0.22 $kgCO_2e/kg$. Despite the large waste volume, the climate impact remains modest. This case clearly illustrates that waste mass and carbon footprint do not always move in tandem.



Finding 4 – **Recovery**: Composting generates positive carbon emissions.
Composting (relatively environmental-friendly food waste treatment): 274.8 kg CO2-eq
→ alternative treatment approaches with lower carbon emissions might be considered

Finding 5 – **Trend**: Daily food waste data tends to exhibit minor fluctuations except for the Fruit stall.
- **Possible reasons** for fruit kitchen waste: variations in consumer demand & periodic procurement and processing practices.
- **Kitchen waste**: primarily consists of inedible or unavoidable food components such as chicken bones, vegetable stalks and fruit peels → cannot lead to direct comment on the effectiveness of waste management practices at individual stalls.
- **Plate waste** allocated for the five selected stalls (Green curve): averaging approximately 11.53 kg (172.98 kg/15) per day, reflects food that could potentially have been consumed.

Solution 1: Operator-side Reduction
Based on Renfors (2024) and the Singapore NEA/AVA Guidebook, five operator-side reduction methods are recommended:
- **Menu Planning** – Simplify menus, offer portion sizes, and cross-utilise ingredients. → Jia Xiu Wei Dao: high ingredient overlap cuts waste and emissions.
- **Storage** – Apply FIFO/FEFO, label with dates, and control temperature (<5 ° C or >60 ° C).→ Findings 3 & 5: poor rotation and temperature swings drive spoilage.
- **Kitchen Prep** – root-to-leaf, nose-to-tail, train staff, and cook in small batches. → Chicken Rice: good practice, but high impact bones remain a challenge.
- **Service** – Use smaller plates, advertise free refills, offer last-hour discounts, and give doggy bags. → Chicken Rice: Portion control reduces plate waste.
- **Procurement** – Assign a buyer, use digital inventory, and order small batches frequently. Prevents over-purchasing and spoilage.

Solution 2: Intervention
Based on Radhakrishnan et al. (2024) and Liechti et al. (2024), five interventions are recommended:
- **Portion reduction + free refills** – Cut servings by 25-40% and offer free refills. Increases clean plate rates from 73% to 80%. → Chicken Rice (Finding 2), where small portions left little plate waste.
- **Trayless dining** – Remove trays; customers carry plates by hand. Cuts food waste by 32% and liquid waste by 47L/week. Directly targets tray return waste.
- **Smaller serving utensils** – Use smaller spoons/tongs. Reduces total waste by 17% when combined with signage. Useful for self-service outlets.
- **Economic incentives** – Small rewards (e.g., $0.25 per clean plate). Raises clean plate rates by 22%, but risks transactional behaviour.
- **Food sharing platforms** – Share surplus food via social media or school systems. Helps ~15% of food-insecure students. Relevant to Singapore's low-income households; must follow SFA safety guidelines.

Limitations: short-term effects (posters lose impact within weeks), adaptation periods for new plates (2-3 weeks), higher costs with trayless dining (breakage +15-20%, cleaning +30%), transactional behaviour from economic incentives, and cultural variability – suggesting local pilot testing before full rollout.

Solution 3: Valorization
Four primary categories of value-added products derived from food waste, namely **food ingredients**, **nutraceutical and functional foods**, **bioactive compounds from plants** and **animal nutrition products** (Heng et al., 2024).
Examples:
- **Fruit & vegetable wastes (such as orange peels, kale and spinach) → edible inks for 3D food printing** (Heng et al., 2024; Mubita et al., 2021) **-** Given that the fruit stall generates a substantial volume of waste consisting largely of fruit peels, this approach may represent a viable valorisation pathway while simultaneously creating additional economic value from food waste.
- **Black Soldier Fly (BSF) larvae for food waste treatment -** BSF systems outperform both composting and open dumping, generating approximately -24.8 kg CO_2-eq per ton of food waste treated (Ramzy et al., 2025).

Safety Concerns (Socas-Rodr í guez et al., 2021): limited availability of safety evaluation studies, the potential presence of undesirable substances & the crucial need for comprehensive legislation governing such products.

Solution 4: Redistribution
Discounts & Surprise bags (Treatsure)
Three forms of participation in Singapore' s food waste management (Rut, Davies & Ng, 2020):
- **2nd form -** referred to as **diverse participation**, emphasizes **food redistribution**. Traditional food banks fall within this category, alongside initiatives such as the Ugly Food Platform and the Neighbourhood Food Share Initiative supported by FairPrice Foundation.
- **3rd form - emergent participation**, is largely **citizen-led** and has expanded through developments in information and communication technologies. This form promotes alternative perspectives on food waste management and often involves grassroots initiatives. Examples include community gardens established and maintained by local residents.

CONCLUSION 04

This study examined contemporary food-related challenges and sustainability issues at both the global and Singaporean levels. Through a review of the existing literature on the world and Singapore's F&B sector, key research gaps were identified, which led to the development of the study objectives. Guided by the stages of LCA framework, field data on food waste generation were collected. Based on a set of assumptions, system boundaries, and AI-assisted estimations, carbon emissions associated with different stages of food waste management were calculated and analyzed. The findings revealed five key issues relating to food waste generation at specific stalls, emissions from the recovery stage, and temporal variations in daily food waste generation. By integrating these findings with insights from the existing literature, four categories of solutions were proposed, which cover operator-side food waste reduction, intervention strategies, valorization and redistribution.

Despite efforts to ensure the rigor of this study, several limitations should be acknowledged. Firstly, the assumptions regarding waste classification and composition may have affected the accuracy of the emission estimates. For instance, average plate waste were applied across all stalls, although actual plate waste generation may vary substantially between stalls. In particular, the fruit stall may have generated significantly lower levels of plate waste than assumed. Additionally, the AI-based approximation employed in this study may be subject to an error range of approximately 10-20%. Besides, the emission factor used for the preparation stage did not account for electricity, gas or water consumption due to data limitations. As energy and water use may constitute a substantial proportion of emissions during food preparation, the omission of these factors may have affected the accuracy of emission results. Furthermore, limited access to proprietary databases such as Ecoinvent constrained the selection of life cycle inventory data. Some emission factors were therefore obtained from secondary literature and may not fully reflect local conditions in Singapore. Finally, the study was conducted within a single canteen on campus. As a result, the findings may not be representative of the broader F&B sector in Singapore, thereby limiting the generalizability of the results. Moreover, future research could further investigate the environmental and economic performance of the proposed solutions, particularly operator-side and consumer-side intervention strategies, Black Soldier Fly larvae treatment, food waste valorization technologies, and food redistribution initiatives. Additionally, longitudinal studies could evaluate the effectiveness of these interventions in reducing waste over time.